INNOVATIVE TECHNOLOGY
Summary Report
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Robotic Tank Inspection End Effector

Tanks Focus Area

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INNOVATIVE TECHNOLOGY

Summary Report

Robotic Tank Inspection End Effector

OST/TMS ID 278

Tanks Focus Area

Deployed at
Idaho National Engineering and Environmental Laboratory
Idaho Falls, Idaho

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov/IFD/OSThome.htm under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Idaho National Engineering and Environmental Laboratory (INEEL) has 11 high-level liquid waste tanks at the Idaho Nuclear Technology and Engineering Center (INTEC). The tanks are single-shell, stainless steel tanks contained in concrete vaults. The concrete vaults around the tanks do not meet the necessary requirements for secondary containment, and therefore all of the tanks must be removed from service by the end of 2012. Regulators are requiring that the containment capabilities of the tank structure be established before agreeing to closure proposals. The site is conducting tank integrity inspections to gather information on current tank conditions and to establish loading limits for future remediation and closure activities.

How It Works

The Robotic Tank Inspection End Effector (RTIEE), a tool that mounts on the Light Duty Utility Arm (LDUA, OST/TMS ID 85), is also known as the Non-Destructive Examination (NDE) End Effector (see Figure 1). Specifically designed for remote operations in underground hazardous waste storage tanks, the RTIEE is used to perform detailed inspection and analysis of waste storage tank interiors.

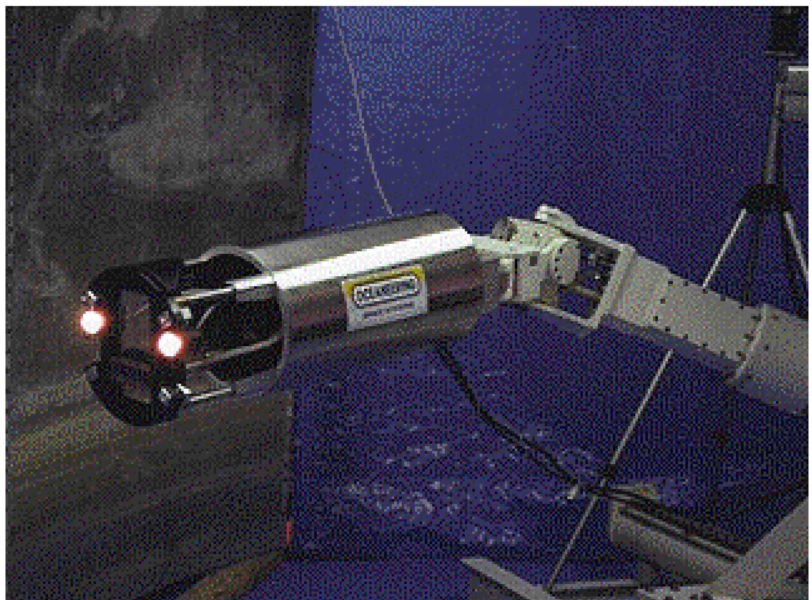

Figure 1. The Robotic Tank Inspection End Effector.

The RTIEE system operates by combining alternating current field measurement (ACFM) with a compact vision and lighting subsystem and an integrated mechanical deployment subsystem. Coupled with positioning data from the LDUA, the RTIEE system can identify defects and permanently record their locations in the tank. The remote operator has live video display during the examination. Data from ACFM are presented as a two-dimensional color plot showing the size and position of the defect. When the operator clicks on the defect shown on the video display, the defect type, size, and position data are instantaneously recorded. For detailed inspection, the RTIEE is positioned against the tank wall and remains stationary during the examination.

Advantages over Baseline

Conventional techniques for assessing tank integrity require insertion of a string of corrosion coupons into the tanks at a fixed radial position at various tank depths. The coupons are removed and analyzed for corrosion. This procedure causes concerns because the corrosion coupons are representative of tank conditions, but are not actually part of the tank structure.

The RTIEE offers several advantages over using conventional techniques, including the following:

- Visual inspection and data collection on the actual tank structure are made possible.
- Remote operations limit radioactive exposure to personnel and the environment.

The following potential disadvantages may affect the selection of the RTIEE for use in tank waste operations:

- Specially trained personnel are required to operate the LDUA and the associated end effectors, including the RTIEE.
- A large amount of support equipment is necessary to perform operations, mostly associated with the requisite LDUA system, but also for the end effectors.
- The resolution of the system will show an existing problem, but it is not sufficient to identify small pits that could potentially evolve into a leak or other structural integrity problem.

Potential Markets

This technology has the potential for use at other U.S. Department of Energy (DOE) sites for in-tank activities. The RTIEE may also be used as is or with enhanced modifications for tanks of many different sizes and types.

Demonstration Summary

The LDUA with the RTIEE was deployed at INTEC on February 12, 1999, to demonstrate its performance in a highly radioactive tank environment. Factory representatives from the vendor—Oceaneering Space Systems (OSS), Inc., of Houston, Texas—worked with INTEC staff during the deployment.

Key Results

The RTIEE was deployed by the LDUA and performed numerous scans with minimal trouble. Because of the short period of time that OSS engineers were available to interpret data, the “fly-by” feature was not tested. The end effector was redeployed on February 24, 1999, and used to scan visible construction defects on the side of the tank. The end effector did not detect the defects, and the operators saved three scans in an electronic file for later analysis by the OSS engineers. After analysis, the OSS engineers suggested that the end effector worked correctly, but the defects were too small to be detected. Hence, further development may be necessary to improve the precision of the ACFM technique. In general, the inspection demonstrated that the structural integrity of the tank was very good. However, the RTIEE did not detect pits that were visually apparent, and tank integrity was evaluated almost exclusively based on the visual inspection.

Participants

The following parties contributed to successful deployment of the RTIEE at INTEC:

- Tanks Focus Area (TFA)
- Industry Programs
- Characterization, Monitoring, and Sensor Technology Crosscutting Program
- DOE Office of Science and Technology (OST)
- DOE Office of Environmental Restoration (ER)
- INEEL
- Lockheed Martin Idaho Technologies Company
- OSS

Commercial Availability

The RTIEE was developed by OSS with funding from the OST under the direction of Industry Programs and TFA. The RTIEE is commercially available through OSS under the product name Robotic Tank Inspection End Effector. U.S. patent for the RTIEE is pending, but it is patented in the United Kingdom under the number UK 990693.8. 2286678A, 2224575.

Future Plans

Use of the LDUA and the RTIEE will continue at INTEC through fiscal year 2012 to sample and inspect up to 10 additional tanks.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov/IFD/OSThome.htm under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for the RTIEE is 278.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

The LDUA and various end effectors are designed for work in hazardous waste underground storage tanks typified by those within the TFA purview. These tanks have limited access and contain an environment inhospitable to humans and most conventional tools. For further detail on the LDUA, see the Innovative Technology Summary Report on Light Duty Utility Arm (DOE/EM-0406). The LDUA is implicitly included as an essential piece of equipment used to deploy and enable operation of the RTIEE.

Goals and Objectives

The RTIEE is used to inspect underground hazardous waste storage tanks for indications of corrosion, cracks, pits, and weld defects prior to sampling of tank contents. The RTIEE can detect

- a wall thickness of up to 0.3125 inches with an accuracy of ±0.05 inches;
- axial or transverse surface breaking cracks of 2.5 to 0.25 inches in length, ±0.125 inches, and 0.125 inches deep, ±0.05 inches; and
- corrosion pitting with a minimum diameter of 0.125 inches and a depth of 0.0625 inches with a measurement accuracy of ±0.025 inches.

Description of Technology

The RTIEE acts as a tool in the gripper of the LDUA. The RTIEE system is composed of three hardware components:

- The end effector—components are depicted in Figure 2 and described in Table 1.
- At-tank electronics—the camera controller, short circuit protection, as well as connections for electricity and the computer system.
- Operator console–a personal computer outfitted with a customized graphical user interface.

The operator controls the RTIEE system from a control trailer and views the video and ACFM inspection data from a personal computer equipped with customized analysis and control software, including an intuitive graphical user interface, as depicted in Figure 3.

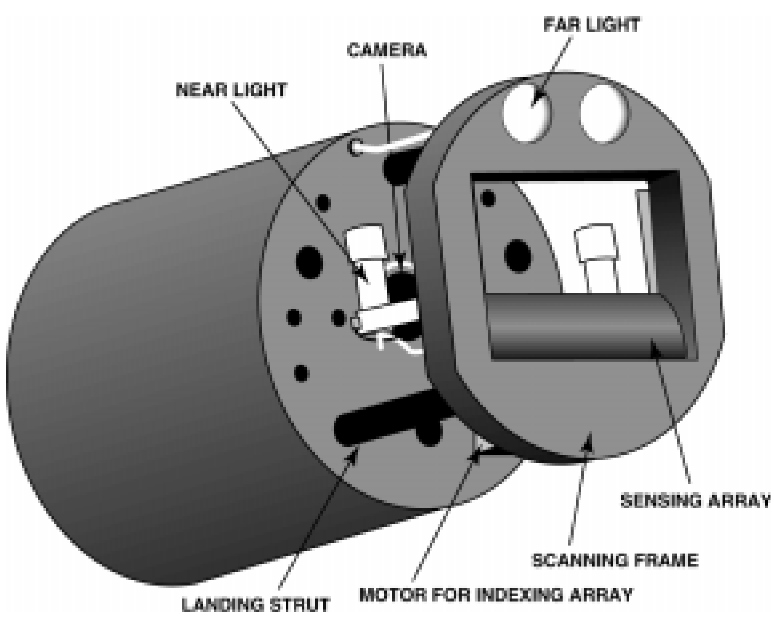

Figure 2. Drawing of the Robotic Tank Inspection End

Basic Principle of the Technology

In the RTIEE, ACFM sensor coils are mounted in a 96-coil sensor array protected by a 0.010-inch stainless steel plate. This sensor array is driven across the RTIEE scanning frame for a detailed, quantified inspection of a 3- by 3-inch area. Data from this detailed scan are used to size any detected defect(s).

Table 1. Robotic Tank Inspection End Effector components

Component	Description	Subcomponents	Function
Main body	Cylindrical housing	Camera and lens	Motor-driven zoom and focus
		Lighting system	Two sets to illuminate scanner and distant objects
		Electronics	Provide power, data, and control functions
Landing struts	Four struts connecting main body and scanner frame	Optical sensors	Provide feedback when end effector contacts tank wall
		Rods	Stainless steel rods sprung in aluminum bronze housing
		Compression springs	Absorb impact
Scanning frame	Mounting platform for sensor array	Solenoids	Coils in front of scanner
		Sensing array	Two rows containing coils
		Landing status indicators	Four sensors that indicate flat contact with wall
		Motor	Drives scanner array up and down

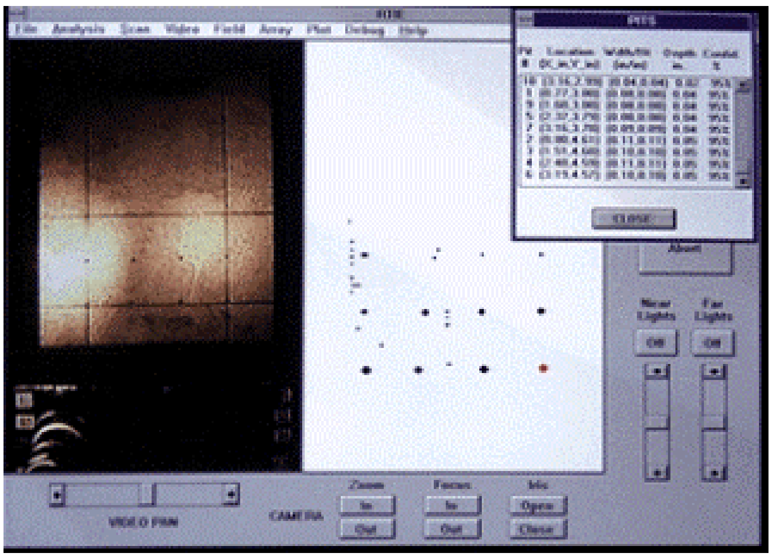

Figure 3. Alternating current field measurement nondestructive examination (ACFM NDE) data displayed on personal computer

The RTIEE uses an electromagnetic inspection technique, ACFM. ACFM is uniquely capable of both detecting and sizing defects in any conducting material by inducing a uniform alternating current (AC) field in the target material and measuring the magnetic fields above the material. The uniform current flow is modeled analytically, enabling the characterization and sizing of defects without the use of artificial defect samples to calibrate the system. The use of the uniform field enables arrays of coils to cover large areas simultaneously, even when relatively small defects are targeted. ACFM does not require electrical contact or an interface with the tank wall surface.

System Operation

To reduce worker exposure, the RTIEE is operated remotely from the control trailer outside the tank radiation area with assistance from several in-tank video cameras not mounted on the LDUA and deployed through other tank risers.

Operational Parameters and Conditions

Operational constraints for the RTIEE center around the operating environment. The RTIEE is designed to withstand temperatures 0–50°C, and its radiation tolerance is 1 million rad. It requires neither clean surfaces for inspection nor any contact with the surface being inspected. The RTIEE introduces no extra by-products in the inspection process. Also, it is slightly positively pressurized (less than 1 pound per square inch) to perform inspections below liquid waste levels. Because the equipment is deployed inside an underground tank, severe weather is not a concern. If winds are high, the LDUA mast can be lowered from the vertical position to prevent damage to the system.

Materials and Labor

The RTIEE requires electricity to operate. Other expendable items consist of decontamination water generated during extraction of the LDUA. Decontamination water is left in the tank.

Two operators control the LDUA system from within the control center: one operates the LDUA while the other operates the installed end effector and the video displays and recorders. Two additional personnel perform end effector changes and decontaminate the LDUA and end effectors during removal from the tank.

Technical Skills/Training

Because the RTIEE and the LDUA system are unique, special training is required to ensure safe operation. For the INEEL deployment, the system operators developed, verified, and practiced operating procedures in cold-test facilities, as shown in Figure 4. Training took place from April to November 1998 in the Fuel Processing Restoration facility at INTEC. The utility arm was extended into one of the large basement chambers for operators to practice using the robotic arm and end effectors. While two of the operators were at the controls, the others were in the other basement chamber watching the arm move. This procedure helped all operators get a feel for how the arm worked and how to control it. During this time, key craft personnel were also trained to support setup, takedown, and maintenance of the equipment.

Figure 4. System operators train using the LDUA in a cold-test facility.

Secondary Waste Considerations

Most of the secondary waste, which is governed by the U.S. Environmental Protection Agency, is water used to decontaminate the equipment. DOE is responsible for safe storage and treatment of the waste.

Concerns/Risks

The alternative of using operations personnel to conduct inspections presents a much greater risk of exposure.

SECTION 3
PERFORMANCE

Demonstration Plan

Operation of the LDUA with the RTIEE was demonstrated in February 1997 at the Hanford Site and deployed in February 1999 at INEEL. These tank installations successfully demonstrated surveillance and inspection of both carbon and stainless steel tanks.

Major Objectives

The goal was to develop a single end effector that could perform electromagnetic and visual inspection simultaneously. Other success criteria were as follows:

- Camera and lighting enable unobstructed view of a distant tank wall and close-up view of a tank wall during inspection.
- The scanning frame and strut are safely placed over the target area.
- Scanning algorithms size corrosion pitting at a resolution not less than 0.3 inches wide by 0.3 inches deep.
- The graphical user interface concurrently displays real-time video and inspection.
- All control functions successfully operate using the graphical interface.

The demonstration at Hanford focused on “fly-by” inspection mode. The system collected NDE data over a large area while the LDUA was in motion and determined whether there were any defects or corrosion issues. The deployment at INEEL was to inspect the walls of underground storage tanks from a fixed location for small surface-breaking defects, such as pits and cracks, as well as large defects that could permit a tank leak.

Major Elements and Support Equipment

The LDUA and RTIEE were deployed at INEEL in tank WM-188. A Stereo Viewing System was also deployed for a preliminary visual inspection inside the tank. Representatives of OSS assisted in picking areas of interest for inspection and data interpretation. The LDUA was redeployed a few days later using a sampling end effector to obtain heel samples.
Support equipment for RTIEE deployment included the following:

- LDUA
- at-tank instrument enclosure
- power skid
- containment skid
- utility skid
- control systems and trailer
- end effector exchange system
- decontamination system

The end effector is supported by software written by OSS, which can be used to catalog data and produce a database on any given tank for future evaluation of detected flaws.

Boundaries

Performance of the LDUA and other end effectors is not discussed in this document.

Results

The RTIEE was developed to inspect underground hazardous waste storage tanks for cracks, pits, and wall defects. Since the RTIEE is dependent on the LDUA, the quantitative performance also represents successful performance of the LDUA. This section presents an overall discussion of the RTIEE performance.

Testing

The RTIEE was demonstrated with the LDUA in the cold test facility at Hanford, Washington. On February 4, 1997, the system performed a fly-by NDE inspection on carbon steel sample plates mounted on a simulated tank wall surface. The system demonstrated the ability of a remote operator to locate defect sites based on the combination of the visual feedback and the ACFM data as the end effector was "flown" over the plates. The operator used the ACFM data screens to identify suspected defects, which were seen as light-to-dark patterns in the real-time display. Suspected defect sites were recorded in a tank wall map database along with the manipulator position, providing a graphical representation of the inspection flight path inside the tank along with markers at each of the suspected defect locations observed during the fly-by. The manipulator was then returned to the suspected defect sites for detailed inspections. Values for crack/pit length and depth returned by the RTIEE during the demonstration verified the system's ability to size a 1.5-inch crack within 0.060 inches or 10% (whichever is greater) at a fly-by rate of 1 inch/second.

Deployment

In May 1998, the RTIEE was integrated with another LDUA at INEEL to ensure that both systems would be operational. In August 1998, the RTIEE was scheduled for deployment in a tank containing radioactive liquid waste. When the scope of the project was modified to include submerging the end effector in the waste, it was shipped to OSS for retrofitting to prevent leakage into its internal cavities. In subsequent operation, the end effector maintained a constant negative pressure to prevent leakage and explosion in the event of sparking.

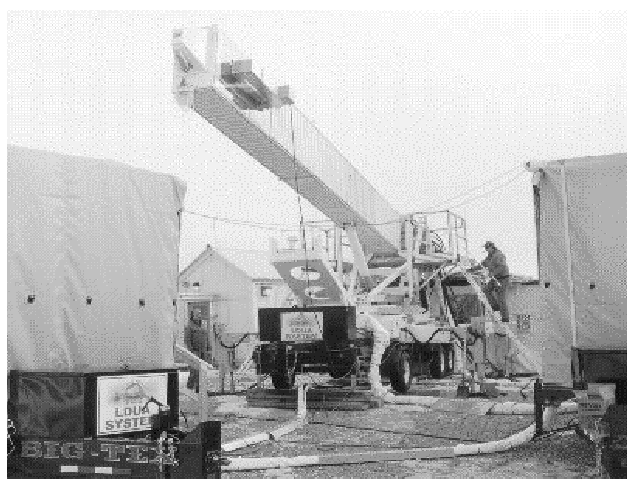

Figure 5. Deploying the LDUA into an underground liquid radioactive waste storage tank at the INTEC tank farm.

On February 12, 1999, the LDUA with the RTIEE was deployed through a 12-inch riser into tank WM-188 at INTEC (see Figure 5). Tank WM-188 is a 300,000-gal underground stainless steel tank, approximately 50 ft in diameter and 45 ft from riser top to tank bottom, containing a residual heel of high-level radioactive liquid waste about 10 inches deep. The deployment occurred under winter conditions with the outside air temperature down to 10°F, snow cover, and occasional wind and precipitation. Operations staff devised an enclosed tent to protect the riser area.

The RTIEE verified minimal corrosion conditions in the tank. The scans and visual inspection revealed some as-yet unknown black material on the tank walls; however, no significant corrosion or cracks were detected. During the deployment, the camera view clearly indicated radiation in the form of "snow," which was due to the bombardment of the camera by the radioactive particles. The "snow" increased when the RTIEE faced the liquid waste. Upon removal from the tank, the end effector was "wiped" and found to be clean. In the initial deployment, the end effector came into contact with only the inner tank walls above the liquid waste. The depth of the waste level was very low (<1 ft). No corrosion defects were noted on the three welds examined.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The compact RTIEE combines tank video and lighting with ACFM electromagnetic inspection. The RTIEE provides real-time detection and sizing of cracks and corrosion pitting in any conductive material. This combination is unlike other systems, which require separate deployments or calibrations to standardize defects. Prior to development of the RTIEE using ACFM, eddy current, X-ray, or ultrasonic techniques were used.

The RTIEE using ACFM provides distinct advantages over alternative systems:

- ACFM is an electromagnetic NDE technique specifically developed to overcome the shortcomings of eddy current techniques.
- ACFM is far less sensitive than eddy current to deviations in standoff distance and orientation.
- Unlike X-ray, ACFM is a benign electromagnetic technique that does not use a hazardous source and does not require interpretation of hard-to-read films.
- ACFM does not produce secondary waste like ultrasonics, which use transmission coupling fluid or gels to transmit sound energy into the target material.
- The NDE system does not require electrical contact with the surface, eliminating the need for surface cleaning.
- The RTIEE system can work through most coatings, including paint, epoxy, rubber, grease, and sludge.

Technology Applicability

The RTIEE can be applied throughout the DOE complex in carbon steel and stainless steel tanks. The RTIEE has many potential applications in preventive maintenance and inspection for repair work of conductive materials. The system could be adapted to reside in a crawler or any other inspection vehicle. Inspection applications include pipelines, ship hulls, pressurized containment vessels, and other types of storage tanks. The system is radiation-hardened and electrically insulated to eliminate sparking in flammable or explosive tanks.

In determining the applicability of the technology for other tanks, parameters that should be considered include the following:

- Access—Risers must be able to accommodate the equipment's dimensions of 10.5 inches in diameter and 19.4 inches in length.
- In situ operations—Obstructions within the tank may hinder the equipment's ability to access desired locations.
- Tank dome loading—Equipment may require support by a load-bearing platform.

- Anomaly size—for INEEL purposes, detection of minute cracks and pits requires higher resolution than what is offered by this technology.

Patents/Commercialization/Sponsor

A Federal Energy Technology Center (now National Energy Technology Laboratory) Research Opportunity Announcement (ROA) in March 1993 invited research proposals for development of this novel storage inspection technology. The ROA was awarded to Oceaneering Space Systems in September 1993, with Technical Software Consultants (TSC) from the United Kingdom as the subcontractor. TSC fabricated the printed circuit cards and assembled the tank-ready sensor array and associated electronics.

Development of the RTIEE included efforts by the following:

- Pacific Northwest National Laboratory
- INEEL
- OSS
- TFA
- Industry Programs

During January 1997, OSS completed work on the tank-ready prototype and shipped the RTIEE system to Hanford for the LDUA cold test. Pacific Northwest National Laboratory personnel performed the mechanical integration with the LDUA and the testing. In November 1997, FETC issued a technical direction letter to complete the radiation-hardened RTIEE. It was delivered to INEEL in April 1998. The High-Level Waste Program accepted ownership of the LDUA and RTIEE, and readiness reviews for its deployment were completed.

The RTIEE is commercially available through OSS under the product name Robotic Tank Inspection End Effector. U.S. patent for the RTIEE is pending, but it is patented in the United Kingdom under the number UK 990693.8. 2286678A, 2224575.

SECTION 5
COST

Methodology

The methodology is to compare the benefit of deploying the RTIEE to that of using the baseline technology. The baseline technology is inspecting tanks by manually lowering corrosion coupons directly below the tank riser. The corrosion coupons are withdrawn periodically and analyzed for corrosion. The costs for deploying baseline technology are likely to be significantly less than for deploying the RTIEE because of the training and deployment costs associated with the LDUA. However, the RTIEE was selected for deployment for the following reasons:

- It generates better tank inspection information. Corrosion coupons show corrosion rates but do not detect and size existing surface defects.
- The LDUA was already being deployed for tank sampling.
- Technology for remote end effector exchange was available so that the Stereo Viewing System and the RTIEE could be used without redeploying the LDUA.

When the cost of the overall project and the consequences of failure were considered, the RTIEE was determined to have positive cost impacts, as discussed in the following sections.

Cost Analysis

Table 2 reports the cost of the RTIEE deployment at INTEC. According to Technology Management System information for the RTIEE, development costs were approximately $2,200K.

Table 2. RTIEE development and deployment costs

Activity	Cost ($K)
Development	2,200
Perform remote inspections to assess tank integrity	250[a]
Project management	70[a]

[a]Includes funds to also perform LDUA tasks required to deploy the RTIEE.

Capital and Operating Costs

The cost to develop the RTIEE was $2,200K, and the cost to deploy it most recently at INEEL was estimated at $300K. A portion of the deployment cost includes some of the costs required to deploy the LDUA to position the end effector. This cost covers labor for the operating crews, project management, and consumable items. Approximately $70K of additional project costs were incurred to manage the project.

Future capital and operating costs will vary greatly depending on the deployment site and the in-tank positioning used to deploy the RTIEE.

Cost Benefits

The LDUA with RTIEE is being used at INEEL to assess the structural integrity of waste storage tanks and to detect cracks and corrosion damage in the wall and weld joints. Data obtained on tank structural condition may enable a less expensive tank closure option to be selected. Without this data, regulators may reject closure options, or unnecessary conservatism could be factored into closure options.

Using the RTIEE results in cost benefits from

- performing inspections remotely rather than imposing risk to workers who manually inspect the inside of the tank,
- using collected data to implement less conservative retrieval and closure alternatives,
- certifying existing tanks rather than constructing new ones, and
- selecting better treatment options.

Table 3 summarizes estimated costs for the various closure options. The estimates address closing 11 tanks, tank vaults, and ancillary piping located in the tank farm facility at INTEC. In the past, the base requirement was clean closure (Option 2 or 3), which is to remove all waste, leave the tank structures in place, and fill the tank voids. The current plan is to perform a risk-based clean closure, if possible, or a landfill closure, as a contingency, (Option 2 or 4), which includes removing the waste and grouting the remaining heel in place. Clean grout will then be used to fill the rest of the tank above the heel level and fill the surrounding vault. The cost differential between these options is over $50 million.

Table 3. Estimated costs of INEEL high-level waste tank closure options

Closure option	Estimated cost ($ millions)
1. Tank removal and demolition closure	5,330
2. Risk-based clean closure, low-level waste grout fill	205
3. Risk-based clean closure, CERCLA waste fill	238
4. RCRA landfill closure, low-level waste grout fill	185
5. RCRA landfill closure, CERCLA waste fill	220
6. Close to landfill standards, clean fill	135

Source: Spaulding, et al. 1998.

Technology Scale-Up

Scale-up is not an issue with the RTIEE. However, inspection of large tanks may require multiple deployments of the LDUA if its reach is not sufficient to inspect suspicious areas.

Cost Conclusions

Using the RTIEE results in cost benefits because the data obtained on tank structural conditions may enable a less expensive closure option to be selected. Furthermore, if the RTIEE reveals that tank structural integrity is acceptable, tanks with little or no waste could be reused instead of building new tanks. The cost of a new tank is $67 million. INEEL will have a need for additional tanks to support cease-use of the tank farm by 2012. Certification of one tank using this technology would fulfill this future need.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The hazardous constituents of tank waste are subject to regulation under the Resource Conservation and Recovery Act (RCRA). Most states are authorized to implement RCRA, including permitting hazardous waste treatment, storage, and disposal facilities.

Some of the tanks within the DOE complex were retired many years ago and contain legacy wastes. These tanks may be subject to remediation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Waste storage and treatment facilities are also required to meet the Clean Air Act and Clean Water Act for liquid and airborne effluents. Requirements are typically implemented at the state or even the local levels for these statutes.

Treatment technologies are sometimes specified within compliance orders, such as Hanford's Federal Facilities Agreement and Consent Order or the Idaho Settlement Agreement signed by DOE and the state of Idaho. These agreements are often limited to immobilization technologies (waste forms) or emission control technologies. There are several examples where agreements and consent orders allow separate decision processes to occur, such as evaluation of alternatives in an environmental impact statement, through which a technical baseline is identified. Finally, engineering trade studies are used to select a specific technology to meet the baseline. These trade studies are performed at a level far more detailed than that typically addressed by regulatory authorities.

Secondary Waste

Most of the secondary waste, which is governed by the U.S. Environmental Protection Agency, is wastewater derived from decontamination of the RTIEE equipment after each use. DOE is responsible for safe storage and treatment of the waste.

CERCLA Evaluation

This section summarizes how the RTIEE addresses the nine CERCLA evaluation criteria.

1. Overall Protection of Human Health and the Environment

    - For tanks containing hazardous or radioactive components, inspecting and monitoring with remote-controlled operations significantly minimizes exposure to workers.

    - Tanks can be isolated faster, with fewer personnel, and in much safer surroundings, thus reducing threats to human health and the environment.

2. Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)

    - The RTIEE with the LDUA was designed and deployed according to applicable regulatory requirements.

    - Established procedures and controls are in place to ensure compliance.

3. Long-Term Effectiveness and Permanence

    - This technology can help accelerate tank remediation and closure schedules.

- The RTIEE is radiation-hardened, with a radiation tolerance of 1 million rad.

- This technology was constructed to withstand temperatures of 0–50^{o}C.

4. Reduction of Toxicity, Mobility, or Volume through Treatment

   - Use of this system makes unnecessary the manual inspection and monitoring of tank integrity, which generate significant amounts of secondary waste due to exposure of additional tools and clothing to radiation sources.

5. Short-Term Effectiveness

   Radiation exposure to workers is maintained as low as reasonably achievable (ALARA) through the following measures:

   - Inspection is controlled and data collected remotely from the tank.

   - The RTIEE combines lights, camera, and positioning system, so fewer deployments into a tank to obtain necessary information are required.

   - Established procedures and controls exist, and workers are thoroughly trained and qualified.

6. Implementability

   - Efficiency and cost are optimized by deploying tools while the LDUA is in a tank for needed retrieval or closure activities.

   - Worker exposure is minimized.

   - Worker training and qualification programs and procedures are in place.

7. Cost data are provided in Section 5.

8. State (Support Agency) Acceptance

   - Both the state of Idaho and EPA are parties of the federal facilities agreement that covers regulatory issues and establishes requirements for management of tanks.

9. Community Acceptance is discussed below.

Safety, Risks, Benefits, and Community Reaction

Because the main components of the RTIEE are operated remotely, there are no major worker safety issues posed by using it. The support equipment includes a decontamination system as part of the LDUA. This feature allows for remote decontamination of the LDUA and the RTIEE. The other support systems are located above the tank and require hands-on operation, but the support equipment does not present any special safety concerns for workers.

Public and stakeholder reaction to the successful deployment of the LDUA and RTIEE in tank WM-188 at INTEC was positive. The technology is viewed as low risk and very promising, provided additional development efforts can increase the resolution, in obtaining characterization data to appropriately close underground tanks as stipulated in the Idaho Settlement Agreement.

SECTION 7
LESSONS LEARNED

Implementation Considerations

Issues discovered at Hanford during the RTIEE demonstration resulted in the following suggestions for future deployments:

- Riser alignment was not performed with the optical alignment scope end effector due to flexibility of the vertical positioning mast and the fact the inner tube was not exactly concentric with the outer tube. Instead, a simpler device was used successfully on the LDUA, which improved the performance of the RTIEE.

- Standoff sensors were integrated into the end effector, providing more precise positional accuracy than LDUA sensors.

- Improvements to the graphic user interfaces and to the ergonomics of some of the components were suggested and completed.

Deployment of the LDUA with the RTIEE at INTEC revealed the following insights that can be applied to future applications:

- Layout drawings of DOE underground storage tanks are typically reviewed to guide deployment of the LDUA and end effectors. Drawings are not always accurate. In the past, when new piping or changes were made to a tank, documentation was not always updated to reflect the changes. Process knowledge can be used to help determine current configurations.

- The LDUA with end effectors, such as the RTIEE, has performed very reliably. Only minor problems have been encountered when compared to other in-tank systems.

Technology Limitations and Needs for Future Development

The RTIEE can be a useful tool for the characterization of other tanks, including 10 other tanks at INTEC, or it can be used for inspections of pipelines and pressurized containment vehicles. However, consideration of the resolution required for each unique application is critical. At INTEC, the RTIEE performed in accordance with specifications; however, in some instances the resolution was not adequate to satisfy inspection requirements for tank certification.

To assist with tank remediation and closure planning of INTEC tanks, INEEL required a technology with the capability to inspect tank integrity beneath the tank heel. The RTIEE was modified during the summer of 1998 to allow submersion to perform below-heel weld inspections on tank bottoms and knuckle regions. Other capabilities, such as cleaning submerged surfaces in preparation for inspection, may be necessary to perform submerged NDEs. The LDUA control systems will also need to be programmed with necessary algorithms and computer code. Testing should be performed using surrogate liquids, slurries, and sludge representative of INEEL and Hanford tank heels.

Further development may be necessary to improve the precision of the ACFM technique for useful application in the INEEL Tank Farm.

APPENDIX A
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APPENDIX B
ACRONYMS AND ABBREVIATIONS

ACFM	alternating current field measurement
ALARA	as low as reasonably achievable
ARARs	applicable or relevant and appropriate requirements
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
ER	(U.S. Department of Energy) Office of Environmental Restoration
FETC	Federal Energy Technology Center
INEEL	Idaho National Environmental and Engineering Laboratory
INTEC	Idaho Nuclear Technology Engineering Center
LDUA	Light Duty Utility Arm
NDE	nondestructive examination
OSS	Oceaneering Space Systems
OST	Office of Science and Technology
RCRA	Resource Conservation and Recovery Act
ROA	research opportunity announcement
RTIEE	Remote Tank Inspection End Effector
TFA	Tanks Focus Area
TMS	Technology Management System
TSC	Technical Software Consultants